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Collapse of Burbot Fisheries in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada

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Abstract.—The burbot *Lota lota* is common in the upstream reaches of the Columbia River Basin in the northwestern USA and Canada. In Idaho burbot are endemic only to the Kootenai River while they also occur in this same river system in British Columbia as well as Kootenay Lake. The Kootenai River and Kootenay Lake once provided popular sport and commercial fisheries for burbot. However, soon after the formation of Lake Koocanusa and completion of Libby Dam in 1972, the respective burbot fisheries in the Kootenai River, Idaho, and Kootenay Lake, British Columbia, collapsed. Our objective was to examine archived data for the Kootenay Lake and Kootenai River burbot fisheries and document their collapse. The environmental degradation of the Kootenai River and its effects on Kootenay Lake are well documented. Some of these effects likely had a direct impact on the burbot populations in the two respective fisheries. The most serious impact is thought to be Libby Dam, constructed by the U.S. Army Corps of Engineers (USACE) on the Kootenai River near Libby, Montana, for hydropower and flood control. Shortly after the dam became operational the fishery in Kootenay Lake rapidly diminished from an annual harvest of over 26,000 burbot in 1969 to none in 1987. Angling regulations for burbot fishing in the lake and river became more restrictive but the fisheries did not recover; eventually both fisheries were closed. The primary reasons for the loss of both fisheries are believed to be high winter flows during the traditional spawning period for burbot and loss of nutrients to the impoundment created by Libby Dam. We propose several recommendations for research to help recover both fisheries.

The burbot *Lota lota* is common in the upstream reaches of the Columbia River Basin in the northwestern USA and in Canada. It is also relatively abundant in the other drainages of western Canada (McPhail and Lindsay 1970). In many locales of northwestern USA and western Canada they are called ling and are a popular sport and food fish. In Idaho burbot are endemic only to the Kootenai River (Simpson and Wallace 1982). They are also endemic to this same river system in British Columbia and Kootenay Lake[a], which is in the basin (Figure 1).

The Kootenai River and Kootenay Lake once provided popular sport and commercial fisheries for burbot. However, soon after formation of Lake Koocanusa and start of operations at Libby Dam, Montana, both fisheries collapsed. Our objectives

[a]Kootenai is spelled Kootenay in Canada.

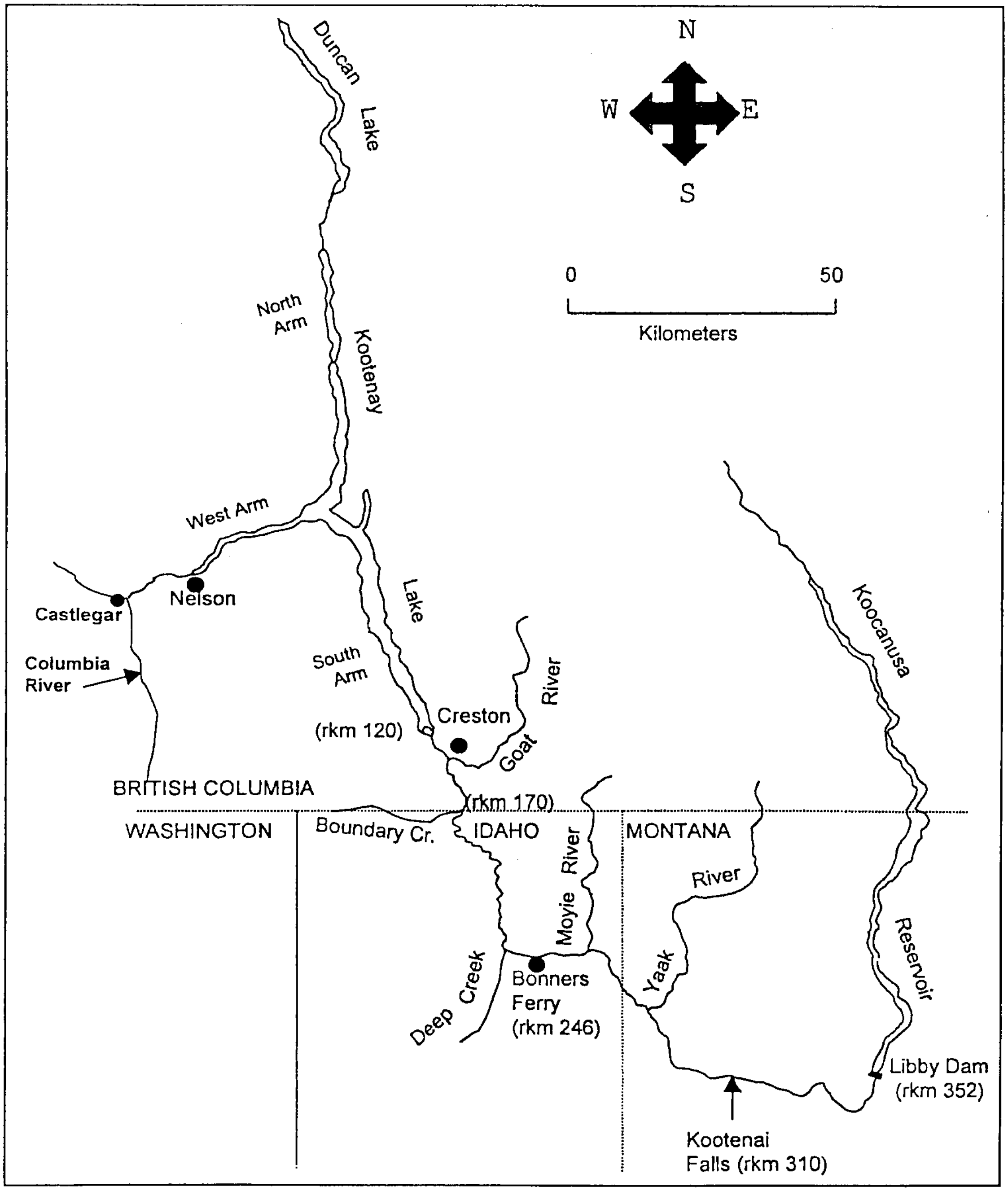

Figure 1. Location of the Kootenai River, Kootenay Lake, Libby Dam, and other major points in British Columbia, Idaho and Montana.

were to examine archived data for these fisheries and document the chronology of the collapse, review harvest and creel data for Kootenai River, review agency catch records for Kootenay Lake and Kootenai River, interview anglers to help document the change in the fisheries, review the literature for plausible reasons for their demise, and to plan reasonable research and management measures that may lead to recovery.

Kootenai Basin

The Kootenai River is part of the upper Columbia River drainage, is the second largest tributary to the Columbia River, originates in Kootenay National Park, British Columbia, and has a drainage of 49,987 km^2 (Bonde and Bush 1975) (Figure 1). From Kootenay Provincial Park Lake the river flows south through British Columbia and into Montana, at Jennings it is impounded forming Koocanusa. From Libby Dam, the river turns west, then travels northwest into Idaho, then north into British Columbia and Kootenay Lake. The river drains Kootenay Lake through the West Arm, and joins with the Columbia River near Castlegar, British Columbia.

The geological history of the Kootenai River system can be traced back to the Wisconsin Glacier and glacial Lake Kootenay (Alden 1953). Colonization of the river with a variety of fish species is thought to have occurred during this period (Northcote 1973). Many anthropogenic changes have occurred since then including channelization, diking, eutrophication, nutrient reduction, and dam construction and operation by the U. S. Army Corps of Engineers (USACE).

Historic Status of Burbot

Kootenai River, Idaho

The earliest records of burbot sampling in the Kootenai River, Idaho were taken from the Idaho Department of Fish and Game (IDFG) Panhandle Region archives. They indicated that Department personnel caught 199 burbot in a period of winter sampling, 1957-1958. The length-frequency distribution demonstrated an abundance of young fish (350-500 mm total length) and a good representation of older fish. The burbot fishery in Idaho was primarily in the winter. The combined average annual catch by the sport and commercial fisheries in Idaho during the 1960s was thought to have exceeded thousands of kgs. For example, the harvest by three commercial fishermen in 1958 was estimated to be over 2,000 kg (Paul Jeppson, IDFG Fisheries Biologist, Panhandle Region archives). Soon after completion of Libby Dam, a substantial reduction in the abundance of burbot was noted. Partridge (1983) captured a total of 108 burbot using three different gear types from 1979 through 1982. He found fewer fish than the archival records, and in 1979 caught only eight fish (one burbot/16 net-d) with a similar amount of effort that was used to catch burbot in the winter of 1957-1958. Although all age groups vulnerable to sampling gear appeared in Partridge's catch, he believed that abundance was substantially lower compared to the late 1950s.

The Kootenai River Fisheries Investigation was initiated in 1993 and was designed to address burbot abundance, distribution, size, reproductive success, movement, and to identify factors limiting burbot in the Kootenai River (Paragamian 1993). A total of only 17 burbot were caught in 1993 (one burbot/33 net-d) and eight in 1994 (one burbot/111 net-d) (Paragamian 1994). However, numerous age groups of fish were apparent in the net catch indicating that some burbot recruitment was occurring. One burbot was sampled between Bonners Ferry and the Montana border and there was no evidence of reproduction in Idaho. Sampling for burbot during the winter of 1993 through 1994 at the mouths of Idaho tributaries was carried out in anticipation of intercepting a spawning run of fish from Kootenay Lake or the lower river; no burbot were caught.

Anglers were interviewed and asked about their fishing experiences, and we reviewed IDFG archives. Anecdotal information indicated an excellent winter fishery was present from the 1950s through the early 1970s. Anglers reported catching many burbot through the ice on set lines. Warmer water temperatures because of the outflow from Libby Dam eliminated the winter ice fishing. Spearing of burbot on spawning runs in tributaries like Snow, Caribou, and Deep creeks accounted for many fish, and there was no departmental limit on the harvest of burbot. Some anglers reported filling gunnysacks with fish. Many of these burbot likely were spawners from Kootenay Lake, British Columbia (Partridge 1983). Burbot regulations in Idaho were very liberal until 1983 when a two-fish daily bag limit was adopted. This was followed in 1992 by a ban on all burbot harvest. The burbot harvest from 1979 through 1982 was estimated at less than 250 fish/year (Partridge 1983). Burbot were nonexistent, even as a nontarget species, in a creel survey that extended from spring 1993 through spring of 1994 (Paragamian 1993; 1994).

Kootenay Lake, British Columbia

We examined archived information from the British Columbia Ministry of Environment Lands and Parks (MOELP) fisheries office in Nelson, British Columbia , for the same time period as the change in the fishery in Idaho. The burbot fishery in Kootenay Lake was primarily a late spring-early summer fishery. Management of burbot in Kootenay Lake was also liberal, with a creel limit of 15 fish/d into the mid 1960s, although in 1967, the limit was lowered to 12/d (Sinclair and Crowley 1969). Burbot were concentrated in the Balfour area of the West Arm of Kootenay Lake, and were vulnerable to angling. The concentration of burbot on the locally known "ling beds" was likely due either to the abundance of *Mysis relicta* used as food and/or spawning habitat (Andrusak and Crowley 1978). Over 26,000 burbot were caught in 1969 and about 20,000 in 1971 (Figure 2). The angling catch rate of burbot averaged about 1 fish/h during this period (Figure 2). Harvest of burbot declined substantially in the following years, and the limit was reduced to 10/d in 1975 (Andrusak 1976). The need for more intensive management was apparent (Andrusak and Crowley 1976) and a potential production and harvest study was undertaken. The findings of the study indicated an optimum sustainable yield of about 12,000 burbot at 14,560 rod hours would sustain the fishery (Martin 1976). The limit of burbot was reduced to five fish/d in 1976 although no improvement in the burbot population was observed. The harvest of burbot continued to decline through the 1970s, although angling catch success remained at about 0.7 fish/h (Figure 2). The burbot fishery collapsed, and as of 1987, no fish have been recorded in the fishery at Balfour; the lake was closed to burbot fishing in 1997. No burbot were caught during two weeks of sampling in the West Arm in 1994 (Paragamian 1994) nor subsequent sampling (Spence 1999).

Without any knowledge of environmental stresses to the burbot fishery, the assumption could be made that overexploitation led to the demise of the population. However, during the same time interval of the collapse as the burbot fishery other fish populations also declined (e.g. kokanee *Oncorhynchus nerka*, white sturgeon *Acipenser transmontanus,* and to a lesser extent rainbow trout *O.mykiss*).

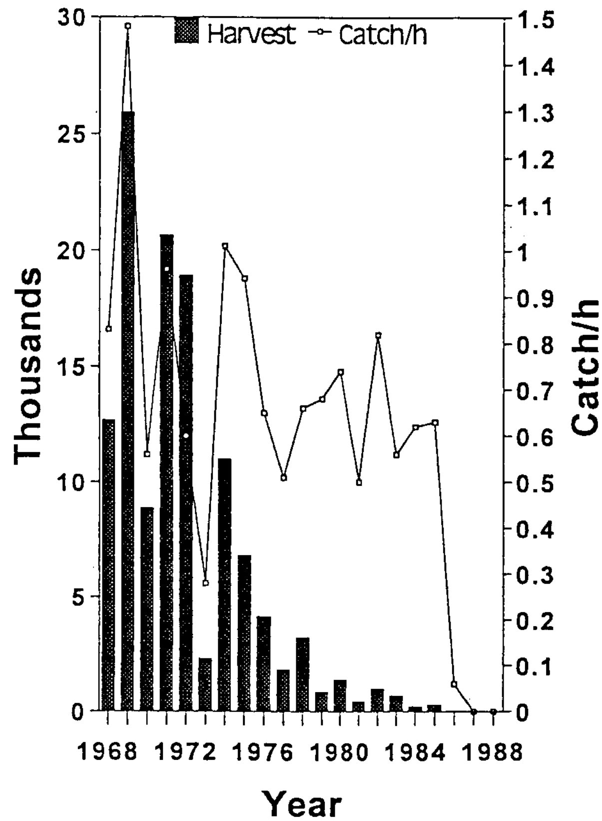

Figure 2. Sportfishing harvest and catch success (fish/h) for burbot from the West Arm of Kootenay Lake, British Columbia.

Cooperative sampling by USA and Canadian researchers in the Kootenai River in British Columbia and Idaho, from 1994 through 1996 (Paragamian 1995; Paragamian and Whitman 1996), indicated that the density of burbot in the Kootenai River diminishes rapidly upstream of the Goat River, British Columbia. Only one burbot was caught from late November 1995 through April 1996 in Kootenai River, Idaho. Hoop nets fished from rkm 145 to 170 during the winter of 1994-1995 yielded only two fish upstream of the

Goat River while 31 additional burbot were caught in the Goat River and downstream during that same period.

Potential Reasons for the Burbot Collapse

Exploitation

Overexploitation of the burbot in Kootenay Lake and the Kootenai River was a concern for fish managers when it became evident the fisheries were at risk of failing. Measures were taken to reduce exploitation by reduction in creel limits and fishery closures but none of these measures restored the fisheries. In contrast to the Kootenai River burbot population may be the burbot fishery in Lake Michigan. The burbot fishery there was on the brink of extirpation because of predation by the invading sea lamprey *Petromyzon marinus* (Smith 1968; Wells and McLain 1973). After development of a selective toxicant for sea lamprey and control of this exotic, the burbot population rebounded without stocking, and their commercial landings increased almost five-fold (Fratt 1991). During the time when burbot populations were depressed there were no reported changes in the environment. Thus, the resiliency of the burbot in Lake Michigan enabled this stock to rebound when habitat was unaltered, whereas the burbot populations in the ecologically disturbed Kootenay Lake and Kootenai River systems have not improved despite fishing closures.

Overexploitation does not appear to have been a factor limiting the recruitment of burbot in the Kootenai River or Kootenay Lake. We examined the length frequency distribution of burbot catches in the Kootenai River, Idaho, and the harvest of burbot from the West Arm of Kootenay Lake, then calculated stock density indices (Fisher et al. 1996) to document any changes in size structure that may have been attributable to overexploitation. For the Kootenai River, Idaho, we calculated proportional stock density (PSD; the percentage of 20 cm in total length and longer burbot that also exceeded 38 cm) for the hoop net catches from the winter of 1957-1958 (Paul Jeppson, IDFG Fisheries Biologist, Panhandle Region archives), the Partridge (1983) sample, and Paragamian (2000). We calculated PSD as well as relative stock density (RSD) for preferred (P; 53 cm), and memorable (M; 67 cm) length burbot (Fisher et al. 1996). We found that PSD remained high from the late 1950s into the late 1990s (1992-1996) in the Kootenai River, Idaho, but RSD-P increased from 18 to 47 to 62. RSD-M also increased from 1 to 20 by the late 1990s. From anecdotal information we believe that angling exploitation was high for the Kootenai River fishery in the 1950s through the 1970s. The burbot PSD from 1957 to 1958 indicates a good representation of young fish (RSD-M; 1, and RSD-P;18) while later the PSD was characteristic of a population that was recruitment limited (RSD-M; 20, RSD-P;62). Had exploitation been a limiting factor the proportion of quality length or longer fish would have decreased. However, the contrary occurred; the proportion of smaller burbot decreased, which resulted in higher RSD values. The Kootenay Lake fishery from 1968 to 1975 was comprised of large burbot (Martin 1976). RSD-P was high (90-100) and even after Libby Dam was constructed it remained at nearly 100, RSD-M was also high (53-84). If angling was a factor we would have expected a decrease in the two larger length categories of burbot, but instead from 1968 to 1975 RSD-M increased from 53 to 81. The increase in the proportion of larger fish suggests a recruitment limited fishery.

Burbot stocks in Alaska have been shown to be vulnerable to overexploitation (Vincent-Lang 1993; Mills 1994). However, after restrictive angling regulations and closures were applied to these fisheries the burbot populations in at least some lakes responded with improved age structures and densities (Taube and Bernard 1995). The burbot fishery in Columbia Lake, British Columbia, also declined because of overexploitation but recovered after angling restrictions were applied (Bill Westover, Fisheries Biologist BCMOELP, personal communication).

Environmental Degradation

The history of environmental degradation to the Kootenai River and its ecosystem is well documented (Northcote 1973; Cloern 1976; Daley et al. 1981; Partridge 1983; Anonymous 1996). Logging and mining in the drainage have always been an environmental concern, particularly with the release of heavy metals and their subsequent toxicity (Partridge 1983). The natural conditions of the Kootenai River no longer exist. Logging and mining operations as early as the 1880s caused tributary discharge to flash and physically changed the streams and caused siltation (Northcote 1973). Additional disturbances came to the drainage in 1892 with attempts to dike the lower reach of the river and claim land for agricultural uses (Northcote 1973). Mining added to the deterioration of water quality in the tributaries and river, and from 1953 through the 1970s, operation of a fertilizer plant on the St. Mary River greatly increased nutrient loading (Northcote 1973). Most of these physical changes, however, came about many years before the collapse of the burbot fisheries; thus, it is unlikely they could be responsible for such a dramatic decline.

Reduced Productivity

Artificial eutrophication because of pollution from a fertilizer plant on a tributary to the Kootenai River in British Columbia brought about an elevation in productivity, particularly in Kootenay Lake (Northcote 1973). Pollution abatement in the mid-1970s and the impoundment of water and consequential settling of sediment nutrients behind Libby Dam reduced the nutrient loading to the river (Daley et al. 1981; Snyder and Minshall 1996).

If food is limiting, reduced food abundance could result in lower survival of young burbot. Larval burbot can be pelagic (Faber 1970) and feed on a variety of micro and macroorganisms in the water column including rotifers, copepod nauplii, copepods, and cladocerans (Vachta 1990; Ryder and Pesendorfer 1992; Ghan and Sprules 1993). As previously mentioned, after Libby Dam was constructed there was a precipitous decline in the catch of burbot from the West Arm. At this same time ortho-phosphate (ortho-P) plummeted from concentrations of 80 to 90 μ/L^{-1} in the late 1960s to 4 μ/L^{-1} by 1978 (Daley et al. 1981). Ortho-P is an indicator of potential primary production (Jones and Bachman 1974). To estimate how this reduction in productivity may have affected the harvest of burbot, the annual harvest of burbot and ortho-P levels in the South Arm of Kootenay Lake at spring turn-over (Daley et al. 1981) were examined (Paragamian 1994). The resulting analysis suggested that some of the variation in harvest may have been due to reduced productivity of the lake. Reduced productivity of the lake diminished zooplankton densities (Ashley et al. 1996) and this could have been an important factor related to the reduced survival of larval burbot. However, the loss of productivity as a factor in the collapse of burbot remains an untested hypothesis.

Temperature Changes

Disturbance of the Kootenai River ecosystem was heightened by the construction and operation of Libby Dam and impoundment of Lake Koocanusa. Libby Dam was created under an International Columbia River Treaty between the USA and Canada for cooperative water management of the Columbia River Basin. Construction of the dam by the USACE began in 1966; its main purpose is hydropower production, with secondary benefits of flood control and navigation. Impoundment of Lake Koocanusa and regulation of downstream flows began in March of 1972. Temperature also increased by 3°C (Partridge 1983). Under the present operation, the river now remains ice-free during the winter.

We considered the possible consequences of post-dam changes in winter flows and temperature of the Kootenai River downstream of Libby Dam. Burbot are winter spawners and often spawn under the ice in January through March (Becker 1983). Prior to the dam, the Kootenai River frequently froze during these months. Burbot spawn at about 1.5°C, or near freezing temperatures (MacKay 1963; Becker 1983). Since 1974, the winter river temperatures are now 3-4°C as opposed to the pre-dam years when temperatures were near 1°C and less. It seems unlikely that temperature in itself could have led to the demise of burbot because some populations are known to spawn at slightly warmer temperatures, although burbot appear to be attracted to colder water (Paragamian 1995). Recent observations on the North Arm of Kootenay Lake has revealed burbot spawning at about 4°C (Spence 1999).

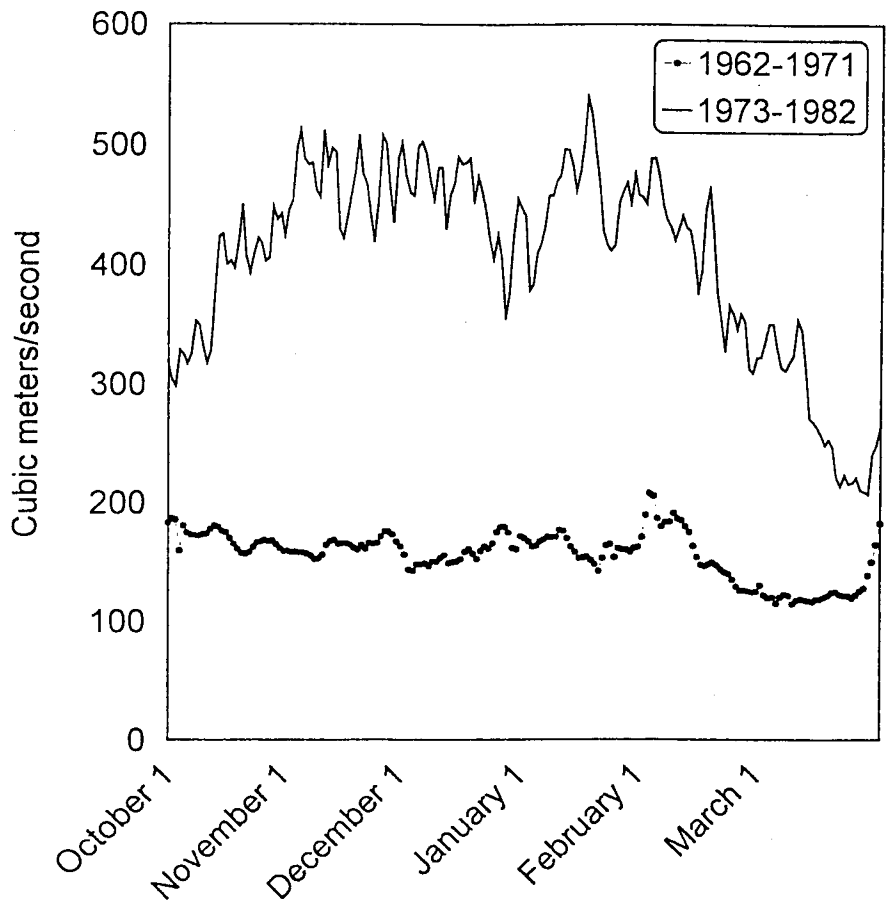

Figure 3. Mean monthly discharge in the Kootenai River at Bonners Ferry, Idaho, from 1962 through 1971 (pre-Libby Dam) and from 1973 through 1982 (post-Libby Dam).

Water Management

As productivity was changing because of pollution abatement and impoundment of Lake Koocanusa, the natural Kootenai River was converted to a regulated system. High summer flows through the West Arm disappeared as a consequence of impounding water in Lake Koocanusa, which affected the prime months for the burbot fishery in the West Arm of Kootenay Lake. The West Arm fishery was unique in that a shallow shelf at the mouth of the West Arm formed a trap for *Mysis relicta*, a food source for burbot (Martin and Northcote 1991).

Hydropower and Flood Control

After completion of the dam, mean monthly flows downstream during spring were reduced by 50%, and winter flows tripled, substantially changing burbot spawning migration conditions (Figure 3). Prior to Libby Dam the natural discharge during January-February of about 170 m^3/s slowly increased in June to a peak spring freshet from melting snow in the mountains that could exceed 2,800 m^3/s. At present, average discharge is higher during September to February than prior to dam construction. Winter hydropower with its power peaking may play a key role in inhibiting populations of fluvial and adfluvial burbot in the Kootenai River from moving to spawning areas and tributaries. Current velocities in the lower Kootenai River are subject to change with daily winter operations at Libby Dam, and velocity increases are directly proportional to flow increases and the elevation of Kootenay Lake. Burbot are weak swimmers and have a low endurance for extended periods of increased flow with a critical velocity of about 24 cm/s (Jones et al. 1974). Flows in the

Kootenai River at Copeland, Idaho above 255 m^3/s produced average current velocities higher (>24cm/s) than the critical velocity for burbot (Paragamian 1995). Flow near the Idaho/British Columbia border can often be as high as 510 m^3/s during normal winter operations of Libby Dam. Burbot can move extensive distances during the winter to spawn (McCrimmon 1959; Morrow 1980; Breeser et al. 1988; Evenson 1993); in some systems they move as far as 125 km to spawn (Breeser et al. 1988). The winter months are normally the most environmentally stable times of the year, which would allow weak swimmers such as burbot the opportunity to travel great distances to spawn. In the Kootenai River, traditional spawning tributaries in Idaho are 50 to 120 km from Kootenay Lake. Tagging and telemetry studies in the river have shown that burbot move freely between the lake and the river in Idaho, providing flow conditions are low. Paragamian (2000) provided telemetry data that indicated high flows during the winter inhibit spawning migrations of burbot in the Kootenai River. In addition, biopsies of post-spawn female and male burbot indicated that all burbot examined did not spawn and were resorbing gonadal products (Paragamian 1994; Paragamian and Whitman 1996; Paragamian and Whitman 1999).

These data and the timing of the collapse with the operation of Libby Dam implicates winter hydropower and flood control operations as important factors responsible for the collapse of the burbot populations. McPhail (1995) stated "although burbot populations often increase after impoundment, the downstream effects of impoundment can be detrimental." Burbot are plentiful in Lake Koocanusa, Montana (Don Skarr, Montana Department of Fish, Wildlife, and Parks, personal communication) and make up a portion of the fish entrained through Libby Dam (Skarr et al. 1996). High flows very well could have altered their behavior, disrupted the spawning synchrony of burbot [they are considered highly synchronized in their spawning (Becker 1983)], and have affected their physiological fitness or spawning readiness.

Research Focus

Winter water management and the loss of productivity/nutrients are two critical changes in the Kootenai River ecosystem that appear to be the most likely reasons for the collapse of the burbot fisheries. Data from the literature and that of the senior author (Paragamian 2000) have shown how these changes could seriously impair the life history processes of burbot. Research efforts should direct attention to locating burbot spawning areas in the system, monitoring adults and their responses to changes in flow during the pre-spawn and spawning season, and focus on environmental factors that may affect early life history. Restoration of burbot will depend on providing a favorable travel corridor for burbot and suitable spawning and rearing conditions. In addition, means of restoring the productivity of the Kootenai River and South Arm of Kootenay Lake should also be explored as an additional means for restoring burbot.

Burbot in the Kootenai River and Kootenay Lake are transboundary fish. Recent genetic studies have revealed that burbot from the South Arm of Kootenay Lake and from Idaho are of the same stock but differ from fish in Montana (Paragamian et al. 1999). It may also be important to locate donor stocks of similar genetic and life history traits to recover burbot (should environmental conditions change) and develop insight into the process of refounding burbot stocks. It is therefore of paramount importance that researchers and managers in British Columbia and Idaho work jointly in their efforts to restore burbot.

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